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ABSTRACT

Fatigue may occur when a member is subjected to repeated cyclic loadings. The fatigue phenomenon started in the form of cracks developing at the critical locations in the structure. Structures subjected to repeated cyclic loadings can undergo progressive damage which initiated by the propagation of cracks. This damage is called fatigue and is represented by a loss of resistance with time. The good mechanical properties of aluminium-alloy in many fields result in the importance of research on this material under fatigue loadings since the imperfection of aluminium-alloy with defects significantly weaken its performance in service. Thus, the understanding of aluminium-alloys behaviour with SCFs is important. In this thesis, aluminum-alloy plates are used to conduct experiment to determine its fatigue performance under notched condition. A total of 23 test specimens were fabricated according to the specified design in ASTM standard for the U and V-notched specimens for tensile and fatigue tests. Certain machining processes have to be considered in order to prepare the test specimen to the required dimension. Based on the dimensions of U and V-notches the values of stress concentration factors were determined. The mechanical properties of materials were determined to obtain the ultimate and yield strengths. The fatigue test was conducted at constant R-ratio by using the Universal Testing Machine (UTM). The results obtained from these studies are plotted as the S-N curves and the fatigue strength of the notched specimens are determined. Based on the overall results, the fatigue strength of U-notched specimen is higher than V-notched specimen. It can be said that the higher value of stress concentration factor result in shorter fatigue life. However, there are differences between the experimental and theoretical fatigue strength for the test specimens due

to a number of factors which include stress raiser, surface condition and stresses applied. Finally the fatigue fracture surface is analyzed where it shows three different regions.

ABSTRAK

Keletihan mungkin berlaku apabila sesuatu objek tertakluk kepada beban kitaran berulang. Fenomena keletihan menunjukkan bentuk retak membangun di lokasi-lokasi tertentu dalam struktur. Struktur tertakluk kepada ulangan beban boleh menjadi kerosakan progresif yang bermula dengan penyebaran retak. Kerosakan ini dipanggil keletihan dan diwakili oleh kehilangan rintangan dengan masa. Sifat-sifat mekanik yang baik aluminium aloi dalam pelbagai bidang menyebabkan penting penyiasatan terutamanya di bawah beban keletihan kerana ketidaksempurnaan aluminium aloi dengan kecacatan ketara melemahkan prestasi dalam permohonan. Oleh itu, pemahaman aluminium aloi dengan SCFs adalah penting. Dalam tesis ini, plat aluminium aloi yang digunakan untuk menjalankan eksperimen untuk menentukan kesannya terhadap keadaan bertakuk. Sebanyak 23 spesimen ujian telah direka mengikut reka bentuk yang dinyatakan dalam ASTM standard untuk U dan V-spesimen bertakuk untuk ujian tegangan dan keletihan. Proses pemesinan tertentu perlu memberi perhatian dan perlu dilakukan untuk menyediakan spesimen yang diperlukan dalam ujian tegangan dan keletihan. Dimensi U dan V-takukan akan ditentukan untuk menentukan nilai faktor penumpuan tegasan. Sifat mekanik bahan ditentukan untuk mendapatkan tekanan muktamad dan tegasan alah. Ujian keletihan dijalankan dengan menggunakan Universal Testing Machine (UTM) dengan perisian komputer dan ujian dijalankan pada nisbah tekanan yan tetap. Data yang diperolehi dari kajian ini diplot dalam SN graf dan kekuatan keletihan boleh ditentukan dengan SN graf. Berdasarkan keputusan keseluruhan, kekuatan keletihan bagi spesimen U-bertakuk adalah lebih tinggi daripada spesimen V-bertakuk. Ia boleh dikatakan

bahawa nilai yang lebih tinggi antara faktor penumpuan tegasan memberikan bahan dengan kehidupan yang lebih pendek. Walau bagaimanapun, terdapat perbezaan antara eksperimen dan teori kekuatan keletihan bagi spesimen ujian kerana beberapa parameter termasuk pembuka tekanan, keadaan permukaan dan tekanan dikenakan. Akhirnya permukaan patah keletihan dianalisis terutamanya dengan tiga kawasan yang berbeza.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

S-N Curve	-A curve of stress amplitude versus number of cycle
SCFs	-Stress concentration factors
$\Delta\sigma$	-stress range
σ_{mean}	-mean stress
σ_{amp}	-stress amplitude or alternating stress
R	-stress ratio
A	-amplitude ratio
σ_{max}	-maximum stress
σ_{min}	-minimum stress
AA	-Aluminum Association
K	-stress concentration factors
K_t	-Theoretical stress-concentration factor
ASTM	-American Society for Testing and Materials
α	-angle of notch
$K_{t\alpha}$	-Stress concentration for notch of angle α, with other dimensions the same
K_{tn}	-Stress concentration for straight- sided notch with semicircle bottom
ISO	-International Organization for Standardization
JIS	-Japanese Industrial Standard

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Fatigue is a leading cause of failure in mechanical components and structures that are subjected to repetitive loads which is below the yield stress. Fatigue on metal means the metal parts is subjected to cyclic stress or formally known as repetitive loads and the metal will fail at a much lower stress which the part can withstand under the application of a single static stress. Failures that occur under repeated or cyclic stresses are called fatigue failures. Failure is the end result of a process involving the initiation and growth of a crack, usually at the site of a stress concentration on the surface.

Fatigue failure is a result from the repeated applications of stress below the tensile strength of the material. The failure process consists of initiation of one or more cracks, the propagation of a dominant crack, and final separation. Fatigue cracks usually initiate at the surface. Therefore, the conditions of the surface and the environment are important factors influencing fatigue behaviors. Three basic factors are necessary to cause fatigue failure such as maximum stress, large enough variation or fluctuation in the applied stress and sufficiently large number of cycles of the applied stress. In addition, there are a host of other variables such as stress concentration, corrosion, temperature, overload, metallurgical structure, residual stresses, and combined stresses, which tend to alter the condition for fatigue.

Fatigue testing can be considered as simply applying cyclic loading to test specimen to understand how it will perform under similar conditions in actual use. The load application can either be a repeated application of a fixed load or simulation of in-service loads. In many applications, materials are subjected to vibrating or oscillating forces. The behavior of materials under such load conditions differs from the behavior under static load. Therefore, engineers are faced with predicting fatigue life, which is defined as the total number of cycles to failure under specified loading conditions. Fatigue testing gives more accurate data to predict the in-service life of materials.

A most influential fatigue research and extensive fatigue test programs were carried out by Wohler, a German railroad engineer in era (1858-1870). J. McEvily (2013) claimed that, Wohler was primarily interested in determining the maximum stress amplitude below which an axle would not fail. Because of pioneering contributions to the field of fatigue research, plots of stress amplitude versus fatigue life are commonly referred to as Wohler's curves in Europe. In the United States such plots are known as S-N curves. Engineers can derive the stress level a material can endure for a specific number of cycles from the S-N curve.

According to Schijve (2009), predictions of the fatigue limit of a notched element is a more well-defined problem than predictions of S-N curves. In the field of fatigue limit, it emphasizes of predicting whether a crack will be nucleated at the root of a notch, or whether that will not occur. For several engineering applications that is indeed a design criterion. It boils down to a prediction of a threshold stress level. Notches with a well defined geometry for which the stress concentration factor (K_t) is available or can be calculated. It starts with predictions of the fatigue limit based on the similarity of stress cycle in notched and unnotched specimens. The effect of a mean stress, different types of loading, and the effect of the quality of the material surface (surface finish) are several variables which will be considered as this is mainly restricted to affect on the fatigue limit.

1.2 PROBLEM STATEMENT

Nowadays, aluminum-alloys are being used successfully in a wide range of application, from packaging to aerospace industries. Due to their good mechanical properties and low densities, these alloys have many advantages over other conventional structural materials. Aluminum-alloys with notches and under fatigue loadings significantly weaken its performance in application. Thus, understanding Aluminum-alloys with SCFs is important. As a result of its importance, a series of study and research have been conducted to avoid failure and can be detected at early stage. The magnitude of SCFs will depend on the types of notches used. The aluminum-alloy plates with U and V notches will be tested under fatigue loadings and its fatigue behavior will be observed and recorded.

1.3 OBJECTIVE

The main objective of this research is to determine and understand the fatigue and fracture behavior of thin Al-alloy plates contained U and V notches subjected to fatigue loadings.

1.4 SCOPE OF STUDY

1. Conduct literature study and survey of the research /field of study.
2. Identify fatigue and fracture behavior of thin plate with Stress Concentration Factors (SCFs) for U and V notches.
3. Identify available Al-alloys in FKM lab, prepare and test the specimen under various fatigue loadings and SCFs.
4. Investigate and compare experimental results with predicted data or results obtained by previous researchers.

CHAPTER 2

LITERATURE REVIEW

2.1 CYCLIC LOADING

There are three common types of stresses which are axial, torsion and bending as shown in Figure 2.1. These three kinds of stresses are able to produce three types of stress cycle with which loads may be applied to the sample. According to Yeck (2011), the stress is cycled either the stress fluctuates between maximum and minimum tensile stresses or between maximum tensile stress and maximum compressive stress. There are two types of cyclic loadings which are Constant Amplitude Loading as shown in Figure 2.2 and Variable Amplitude Loading as shown in Figure 2.3.

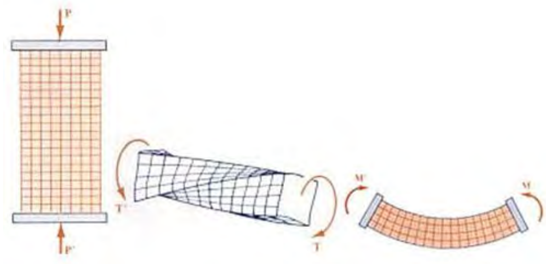

Figure 2.1: Visual Examples of Axial stress, Torsional stress and bending stress

(Source: Syaziyah, 2007)

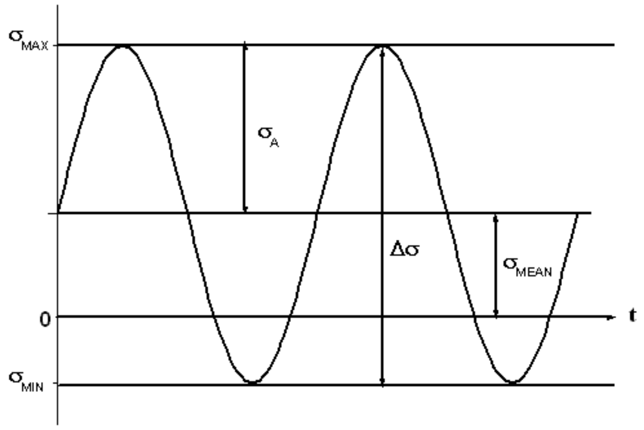

Figure 2.2: Example of Constant amplitude loading

(Source: Syaziyah, 2007)

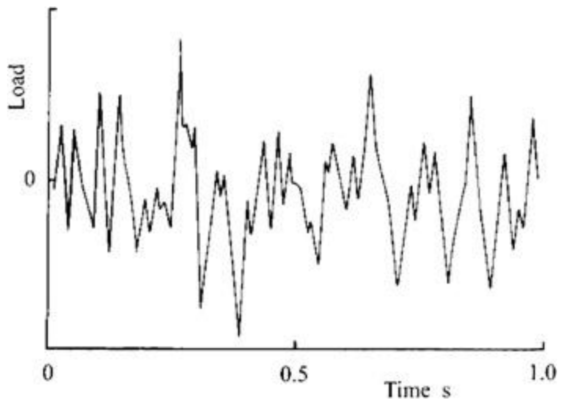

Figure 2.3: Example of Variable amplitude loading

(Source: Syaziyah, 2007)

2.1.1 Constant Amplitude Loading

The Constant Amplitude Loading usually occurs in machinery parts such as shaft rods during period of steady state rotation. The cycling between maximum and minimum stress levels are maintained constant in Constant Amplitude Loading. Nomenclature used in fatigue design has been superimposed on the constant amplitude stress versus time curve as shown in Figure 2.4. Constant amplitude load histories can be represented by a constant stress range, $\Delta\sigma$; mean stress, σ_{mean}; stress amplitude or alternating stress, σ_{amp}; stress ratio, R and amplitude ratio, A. The stress range is the algebraic difference between the maximum stress, σ_{max} and the minimum stress, σ_{min} in the cycle

$$\Delta\sigma = \sigma_{max} - \sigma_{min}$$

The mean stress is the algebraic mean of σ_{max} and σ_{max} in the cycle

$$\sigma_{mean} = (\sigma_{max} + \sigma_{min}) / 2$$

The alternating stress or stress amplitude is half the stress range in a cycle

$$\sigma_{amp} = (\sigma_{max} - \sigma_{min}) / 2$$

$$= \Delta\sigma / 2$$

The stress ratio, R represents the ratio of minimum to maximum stress

$$R = \sigma_{min} / \sigma_{max}$$

The amplitude ratio, A is used frequently in fatigue literature and is the ratio of stress amplitude to mean stress.

$$A = \sigma_{amp} / \sigma_{mean}$$

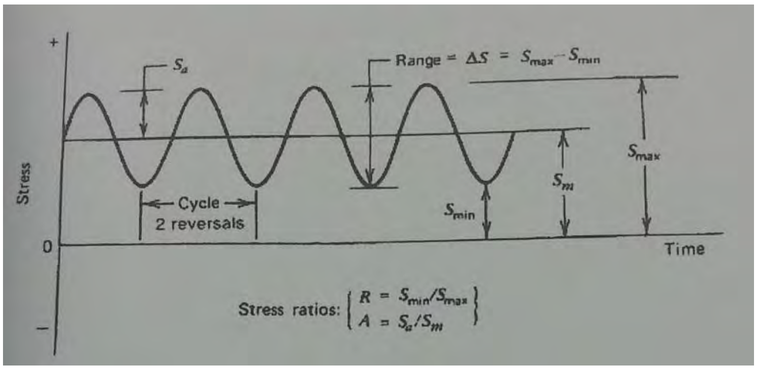

Figure 2.4: Nomenclature of Constant amplitude loading

(Source: Stephens, et al., 2001)

2.1.2 Variable amplitude loading

More complicated sequences of amplitude are required in order to stimulate the stress to which a specimen is subjected in actual service. A realistic simulation is very complicated. These complicated sequences of amplitude we called it variable amplitude loadings. The probability of the same sequence and magnitude of stress ranges recurring during the particular time interval for variable amplitude loading is very small. Unpredictable pattern is the characteristic of this type of load and it cannot be represented by analytical function. The examples for variable amplitude loading are wind loading on aircraft and truck loading on bridges. The unpredictable and diverse load is significant to the cause of fatigue failure as fatigue failure in practical application usually involves stress amplitude that change in an irregular manner.

2.2 ALUMINUM-ALLOY

Aluminum alloys are alloys in which aluminum is predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further heat-treatable and non-heat-treatable and will be discussed in later session. One of the functions of aluminum-alloys in manufacturing fields is aerospace manufacturing since the introduction of metal skinned aircraft that gives properties of light-weight and less flammable.

2.2.1 Types of Aluminum-alloy

There are various kinds of aluminum-alloys and each of them owns its properties. Nevertheless, a classification system for casting aluminum and wrought aluminum alloys were established by Aluminum Association in October, 1954. (Brumbaugh and Miller, 2007)

2.2.2 Casting Aluminum

The International Alloy Designation System is the most widely accepted naming scheme for casting alloys. In the Aluminum Association (AA) system, the second digits reveal the minimum percentage of aluminum, e.g. 150.x correspond to a minimum of 99.505 aluminum. The digit after decimal point takes a value of 0 or 1, denoting to casting and ingot respectively. The main alloying elements in the AA system are as follows:

Table 2.1: Series of casting aluminum

Series	**Components**
1xx.x	series are minimum 99% aluminum
2xx.x	series copper
3xx.x	series silicon, copper and/or magnesium
4xx.x	series silicon
5xx.x	series magnesium
7xx.x	series zinc
8xx.x	series tin
9xx.x	other elements

2.2.3 Wrought Aluminum

Similar to casting alloys, the AA has adopted a nomenclature for wrought aluminum-alloys depend on the composition. Each alloy is given a four-digit number, where the first digit indicates the major alloying elements:

Table 2.2: Series of wrought aluminum

Series	Components
1xxx	series are pure aluminum
2xxx	series are alloyed with copper
3xxx	series are alloyed with manganese
4xxx	series are alloyed with silicon
5xxx	series are alloyed with magnesium
6xxx	series are alloyed with magnesium and silicon
7xxx	series are alloyed with zinc
8xxx	series are alloyed with other elements

2.2.4 Properties of Aluminum and its alloys

The reasons of the widely usage of aluminum alloys are the importance of properties for the predominant metal of aluminum-alloys. Before introducing the properties of aluminum-alloys, the benefits of aluminum have to be understood and well-known.

2.2.4.1 Properties of Aluminum

According to Cobden, R, Alcan and Banbury (1994) stated that there are many useful properties of aluminium.

i. Density: One of the best known properties of aluminium is that it is light, with a density one third that of steel, 2.700 kg/m^3. The low density of aluminium accounts for it being light weight but it does not affect its strength. Weight is important for all applications involving motion. The save of weight results in more payload or greater economy of operation. Low weight combined with the high strength possible with special alloys has placed aluminium as the major material for aircraft construction for the past sixty year.

ii. Electrical Conductivity: Aluminium is an excellent conductor of heat and electricity. An aluminium conductor weighs approximately half as much as a copper conductor having the same conductivity.

iii. Non-Magnetic Property: Aluminium and its alloys are very slightly paramagnetic, as it has a magnetic permeability (m) slightly greater than one. The low magnetic characteristic of aluminium is of value in military ship structure where it has advantages of lightless and lower cost over other non-magnetic metals.

iv. Corrosion Resistance: Aluminium has a higher resistance to corrosion than many other metals owing to the protection conferred by the thin but tenacious film of oxide. This oxide layer is always present on the surface of aluminium in oxygen atmospheres. The Figure 2.5 shows that the degree of corrosion and its effect on strength in two different environments.